E-Health
From Sensors to Systems

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Integrated Systems Laboratory

nano-tera.ch

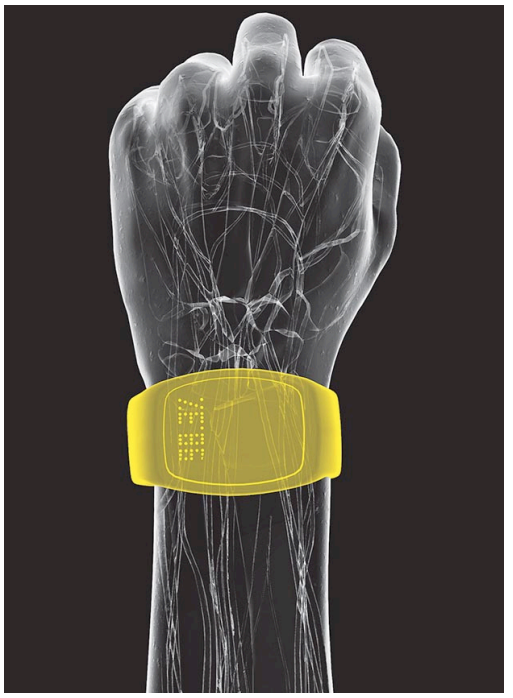
Outline

- **Introduction**
  - **Trends in Engineering and Medicine**
- E-Health
  - Technology issues
  - System issues
- Summary, activities and conclusions

The megatrends

- Relentless growth of computing, storage and communication technologies
  - Inexpensive terminals providing ubiquitous services
- Biomedical science becoming more quantitative
  - Societal need of better care at lower costs
- Big data issues fueling research and businesses
  - Models, algorithms, architectures to tame data deluge

The megatrends: IEEE Spectrum

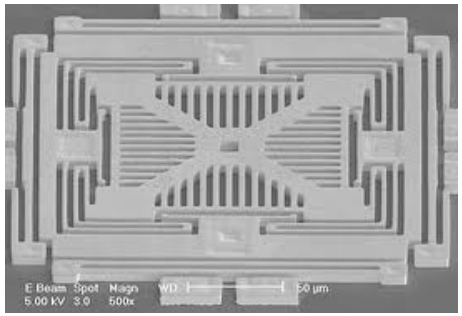


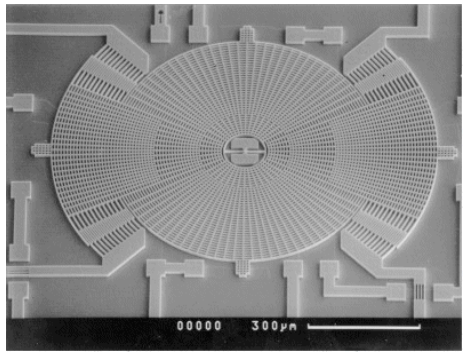
Engineering Trends: The global network

[Courtesy: J. Rabaey]

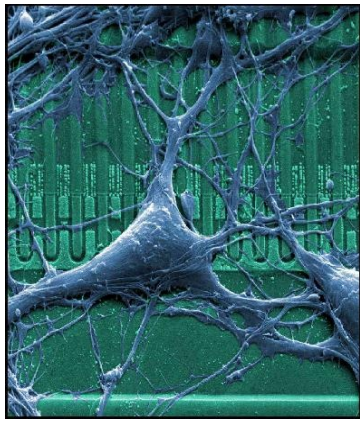
Engineering trends: The sensory interface

- The *More than Moore* revolution:
  - Low-cost volume production
  - Direct interface to information processing systems





[Courtesy: ST]



[Courtesy: EPFL]

What is health?

World Health Organization

State of complex physical, mental and social well-being and not merely the absence of disease or infirmity

treatment

prevention

New medical trends: the 4 Ps

- **P**redictive medicine
  - Predict diseases using “omics” technologies
- **P**articipative medicine
  - Share data and experiences using social media
- **P**ersonalized medicine
  - Adapt diagnosis and therapy to individual
- **P**reventive medicine
  - Quality of aging through nutrition and lifestyle

Where medicine and engineering meet

Sequencing

Personalized drugs

Prosthetics
and implants

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E-health: objectives

- Bettering **medicine** by electronic means
- Bringing **low-cost** medicine to the people
- Exploiting electronic **well-being** as a **lifestyle**
- Opportunities:
  - Synergy of integrated electronic and sensing
  - Platform-based design of electro-sensing systems
  - Mobile telephony as backbone

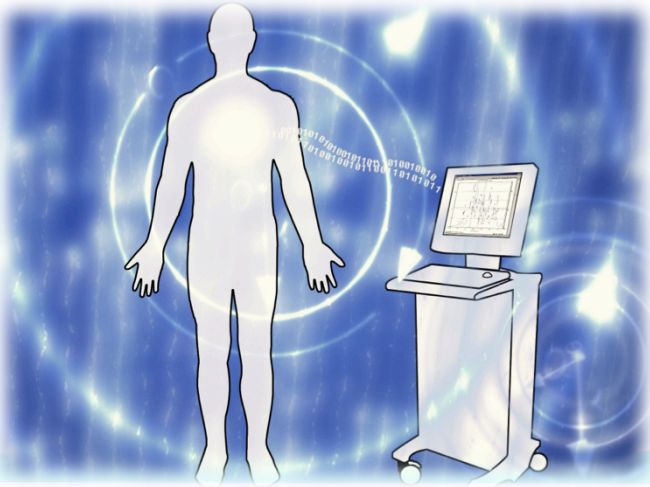
Point of care

- Some molecular tests can be done in real time
  - Efficient and lower cost for routine care
  - Some diagnostics require multiple tests

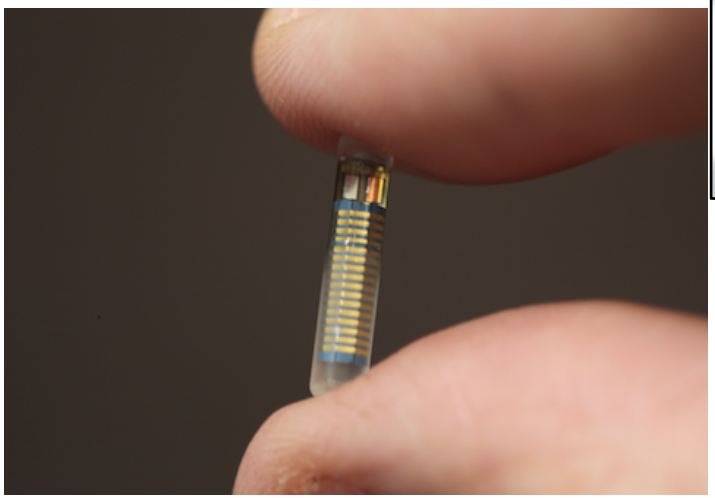
- Emergency situations require real-time measures
  - Patient's fluids are often connected
  - Local tests and remote diagnosis

Tele-medicine: Monitoring chronic patients

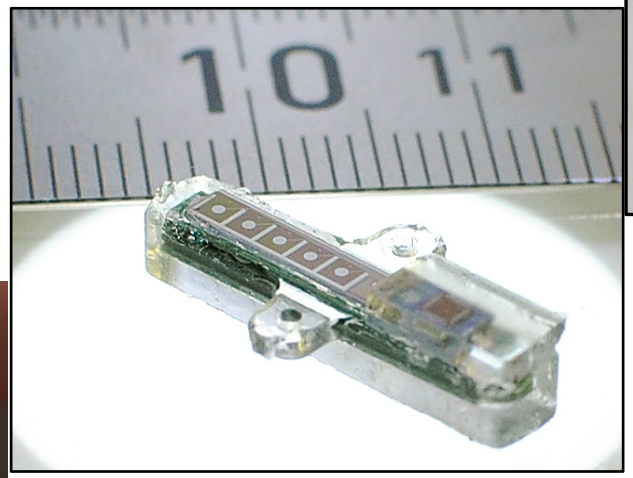
- Non-invasive monitors
  - Heart rate, SpO_2, blood pressure
- Invasive monitors:
  - Metabolites: glucose, lactate, cholesterol
  - Continuous measurements calibrated in *T* and *pH*
- Wireless challenges
  - Secure transmission
  - Remote powering



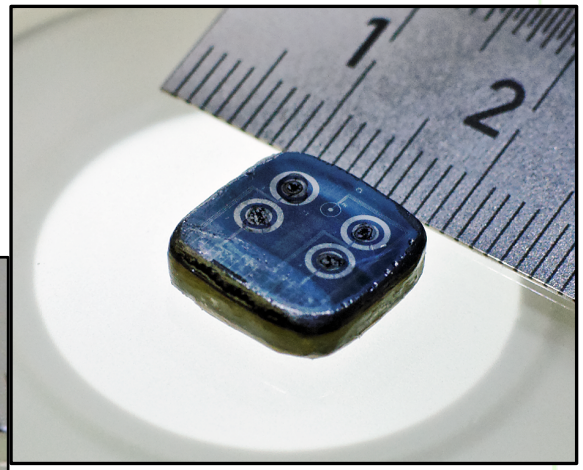
Examples



GLUCOSE SENSOR [Senseonics™]

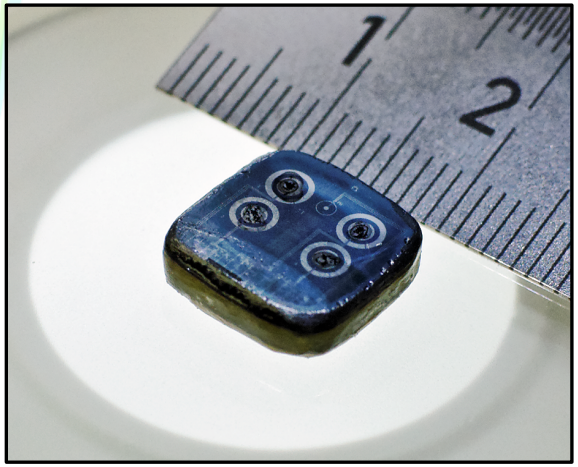


Prototype for human implant [EPFL]

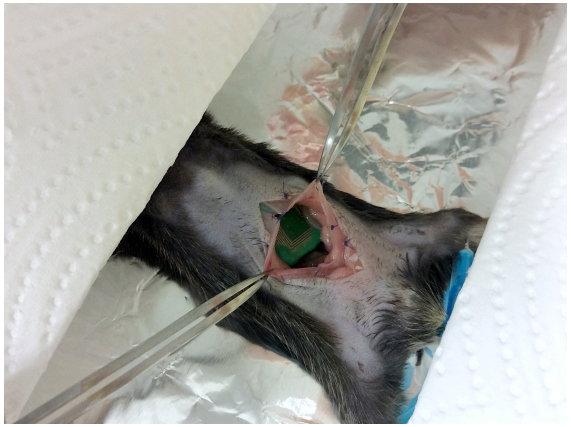


Muti-sensor for lab animals [EPFL]

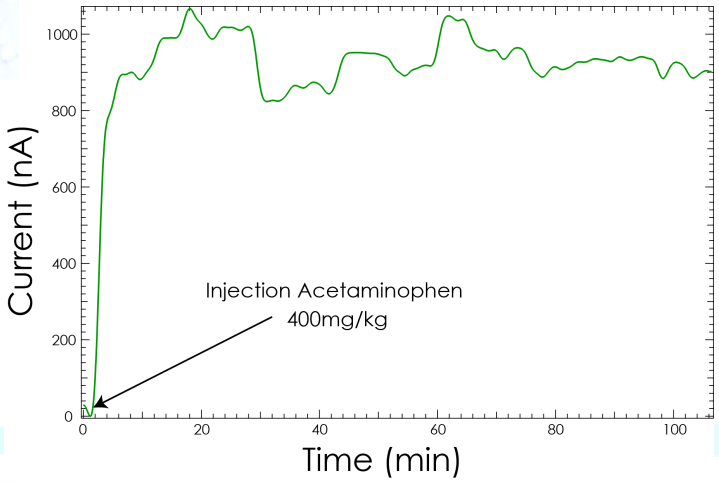
Examples



Muti-sensor for lab animals [EPFL]

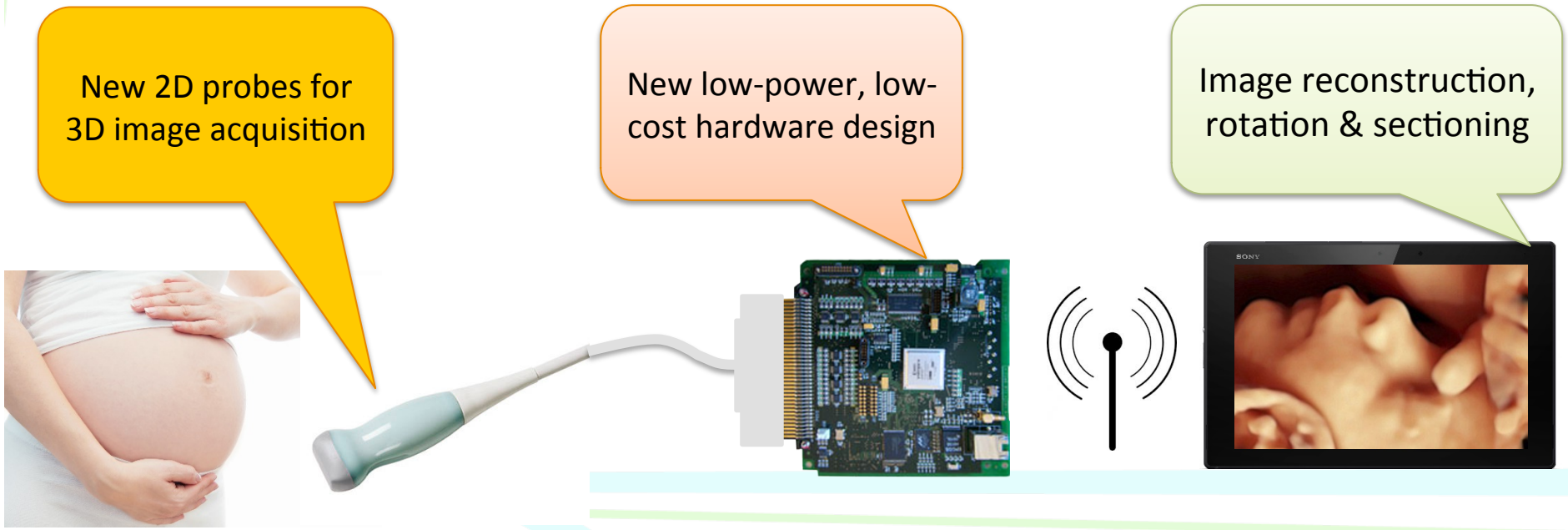


Acetaminophen



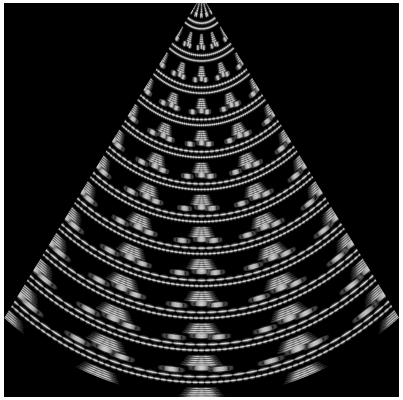
Tele-medicine
Remote ultrasound diagnosis

- Portable ultrasound head & processor
  - Untrained operator acquires 3D volumes
  - Beamforming, compression and transmission
  - Radiologist/Sonographer evaluates images remotely



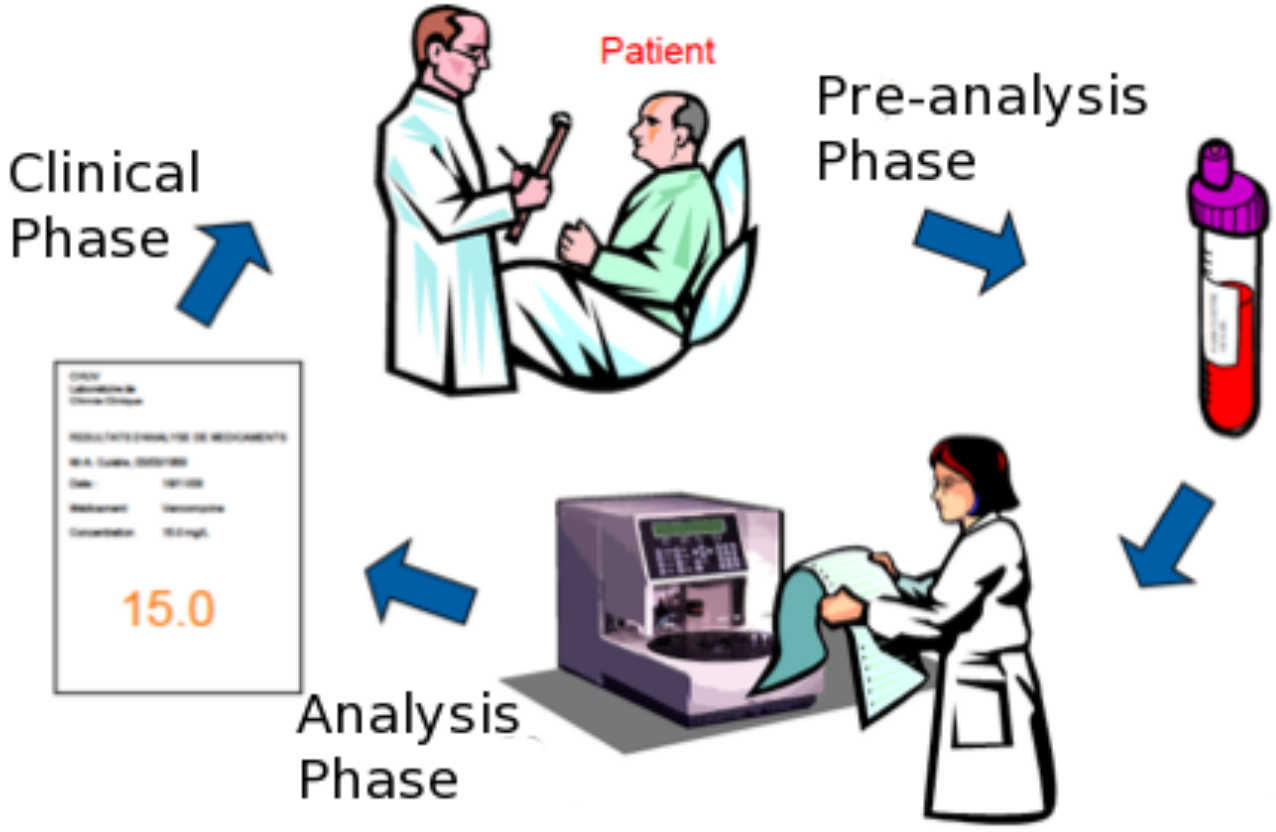
Challenges:
Remote ultrasound diagnosis

- 3D Ultrasound imaging requires supercomputing:
  - TB/sec of bandwidth, GB of storage and TOP/sec
- Electronics should be confined in small volume
  - And directly integrated with the probe
- Wide space of applications, modes and parameters



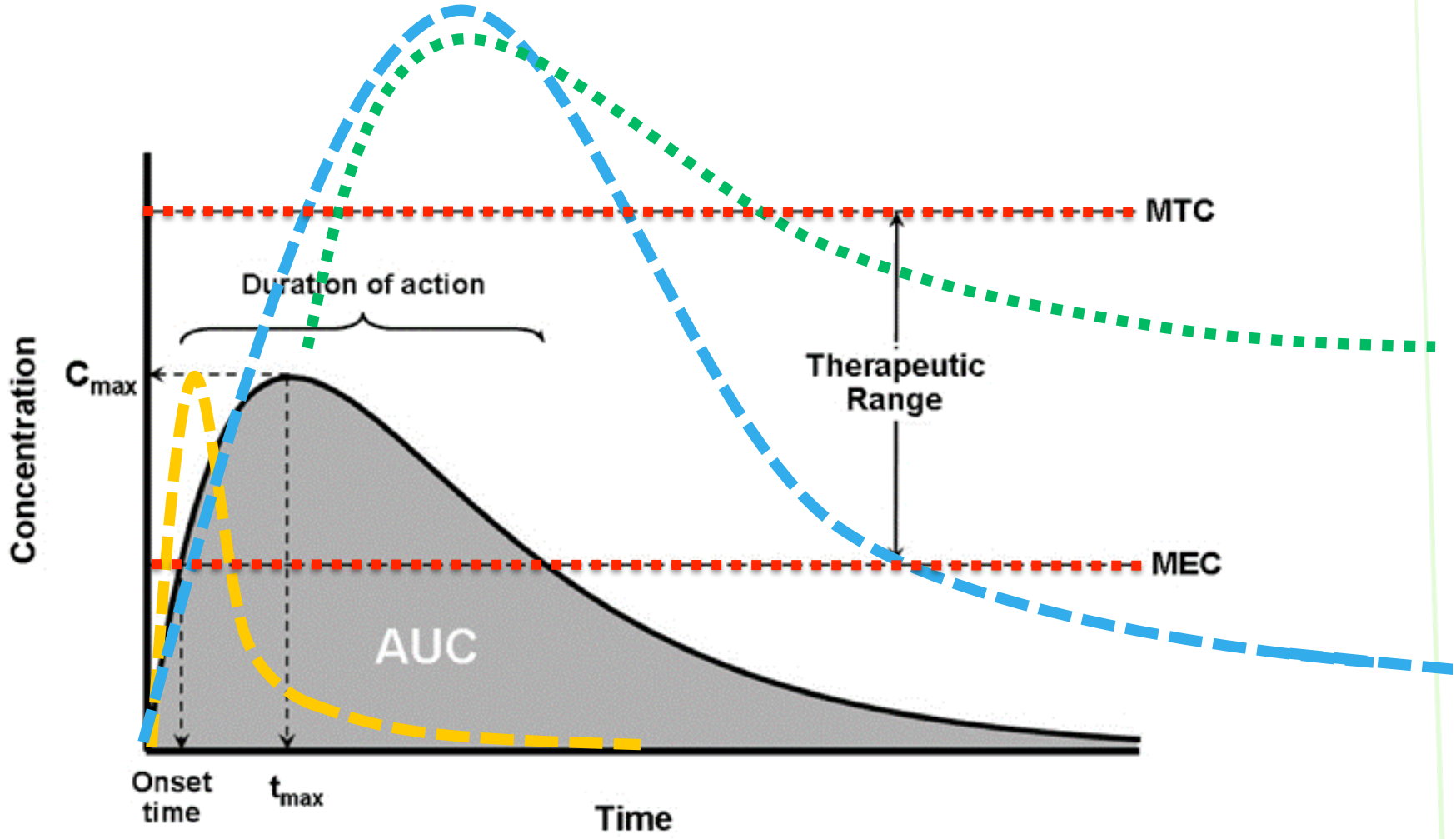
Therapeutic Drug Monitoring (TDM)

- Drug dosage according to the individual *pharmacokinetic profile*



J. Hiemke / European journal of clinical pharmacology 64.2 (2008): 159-166.

Drug concentration in blood



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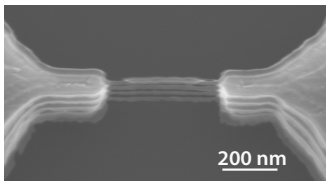
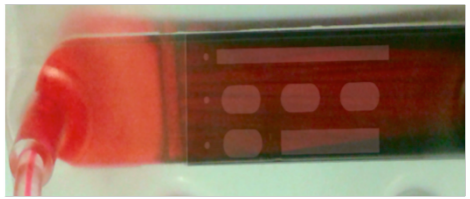
Technologies

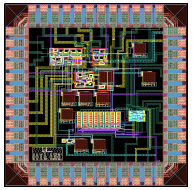
- Sensing
  - Electrical, mechanical, optical



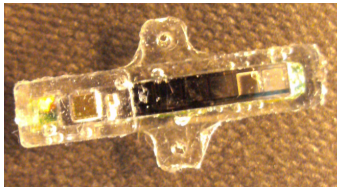
- Fluidics and transducers
  - Micro tubes, valves, pumps



- Data acquisition electronics
  - Discrete, integrated, monolithic with sensor

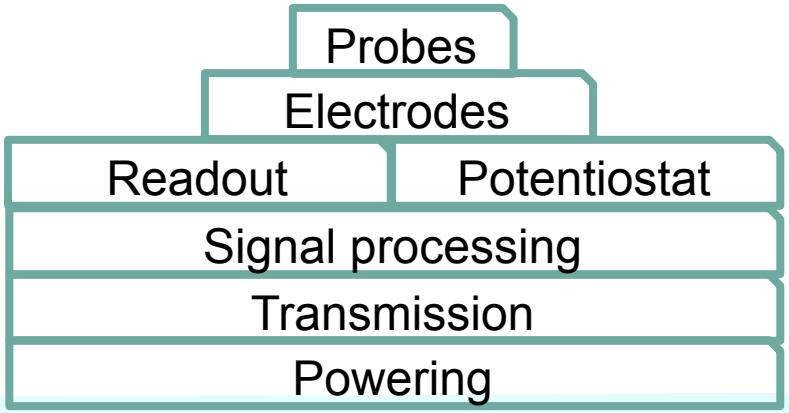


- Packaging
  - Rigid/flexible, bio-compatible



The platform and its components

- Electro-chemical sensors for families of targets benefit from modular integration
  - Similar scalable geometries
  - Different molecular functionalization
  - Different I/V response
- Components can be stored in a cell library
  - Semicustom approach

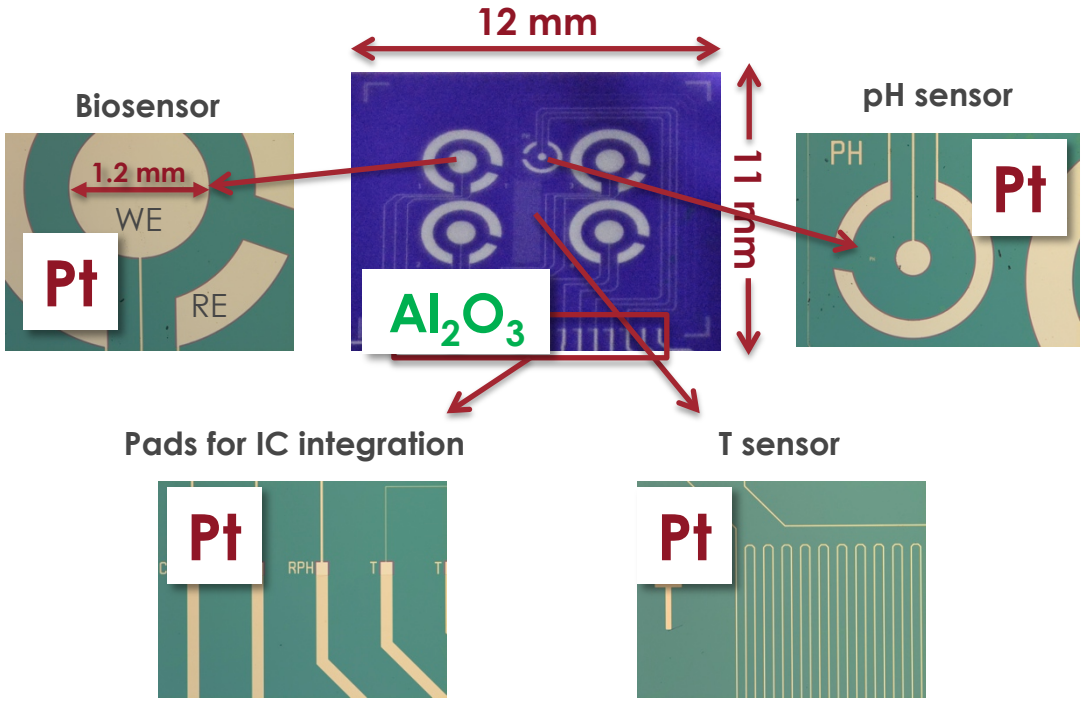


Platform design example

Constraints

- Compact
- Biosensor array
- pH control
- Temperature control
- IC integration
- Easy Fabrication
- Biocompatible

Solutions

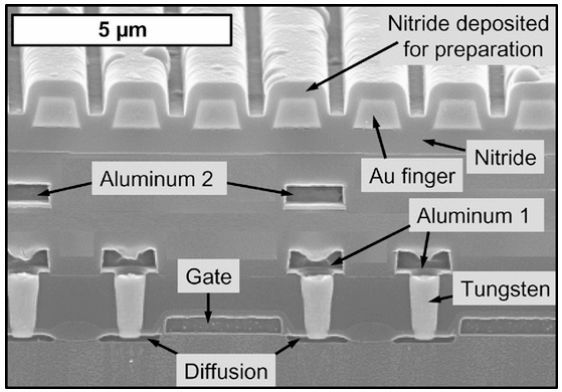


C.Baj-Rossi,et al. Biomedical Circuits and Systems, IEEE Transactions on, vol.8, no. 5, 2014

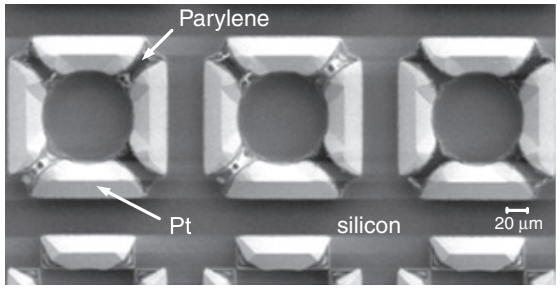
Key points

- Co-design of electronics and sensing is key
  - Achieve low-power consumption
  - Achieve small footprint
- Platform-based design
  - Modularity of design is key to reducing NREs
- Electronic technology can be extended upwards
  - Monolithic integration
  - Silicon interposer technologies

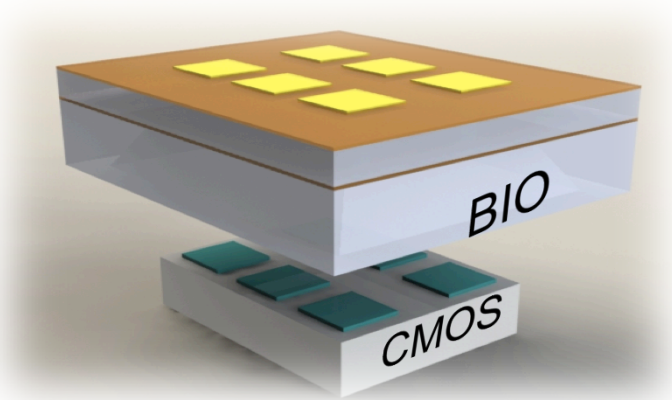
Monolithic and TSV-based integration

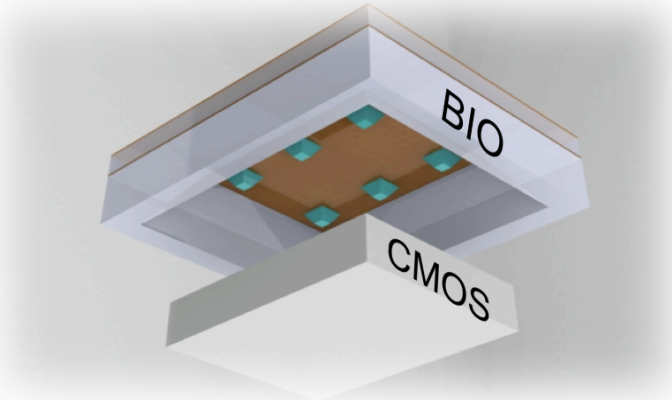


[Schienle et al., JSSC 2004]



[Temiz et al., El Letters 2011]

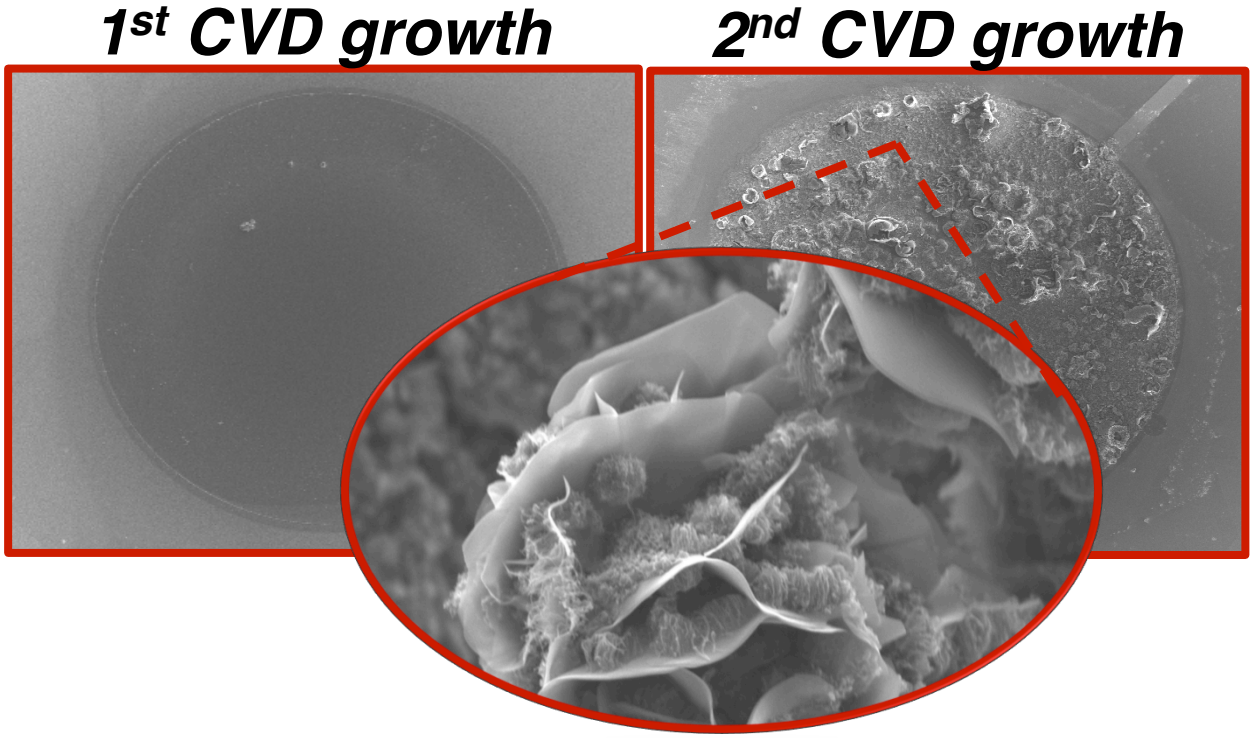




[Temiz et al., Lab on Chip 2012]

CMOS-compatible nanostructuring

- Electrode nano-structuring on top of CMOS
  - Increases sensitivity and lowers LOD
  - Carbon structure growth at 450°C in two steps



I. Taurino, *et al., Nano Letters,* 2014

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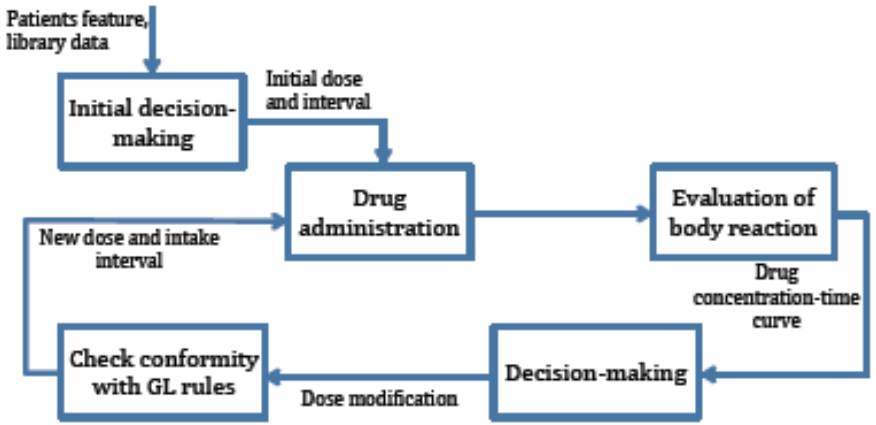
System-level challenges

- Correctness:
  - The system must perform its function in any condition
- Security:
  - No medical information leaking to other parties
  - No access from non-authorized sources
- Safety:
  - Under no condition the health-device can be a threat
  - Safety must be guaranteed for both patient and operator
- Dependability:
  - All devices must work long time in possibly harsh condition
  - Graceful degradation mechanisms

Correctness

- Diagnostic systems
  - Accuracy, linearity, limit of detection
- Drug administration decision support systems
  - Decisions based on acquired data must be correct
  - Life-critical systems

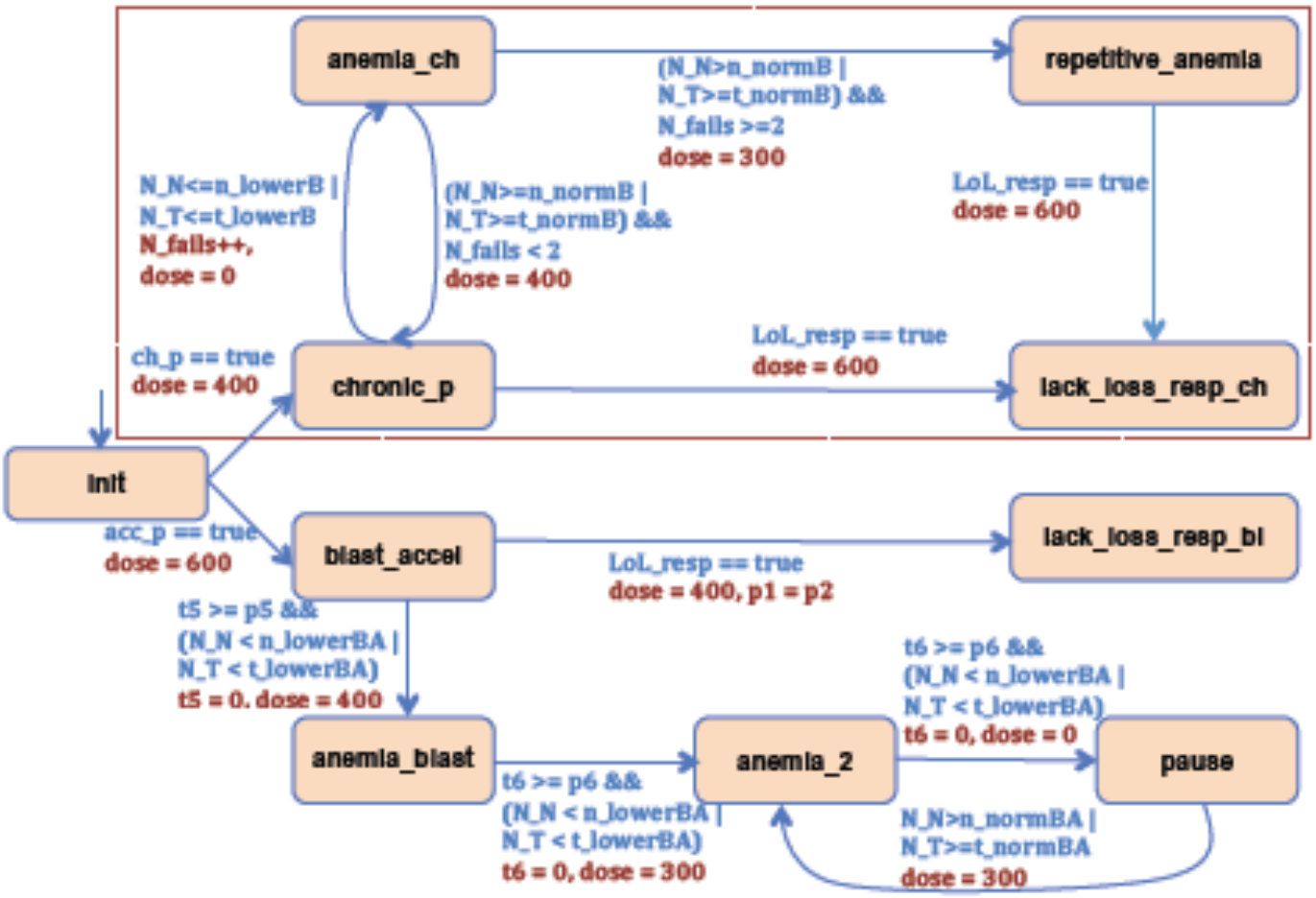


W. You,et al. BioNanoScience, 2013

The verification problem

- Verify that a therapeutic protocol is
  - Consistent
  - Complete
- Verify that a drug administration control unit is a correct *implementation* of the protocol
  - Model checking

Formal model of *Imatinib* protocol



A. Simalastar,et al. International Journal on Artificial Intelligence Tools, vol. 23, no. 3, 2014

Advantages of formal models

- Reason about properties in a formal way
  - Check for invariants
- Synthesize optimal control policies for drug administration
  - Sequence of (time, dose)
- Golden model to verify hardware implementation

Key points

- Very few protocols have a formal description
  - Corner cases are hazardous for patients
- Personalization of drug dosage is important
  - But still used in few cases
- Modeling human body reaction is critical
  - But often hard to achieve in a deterministic way

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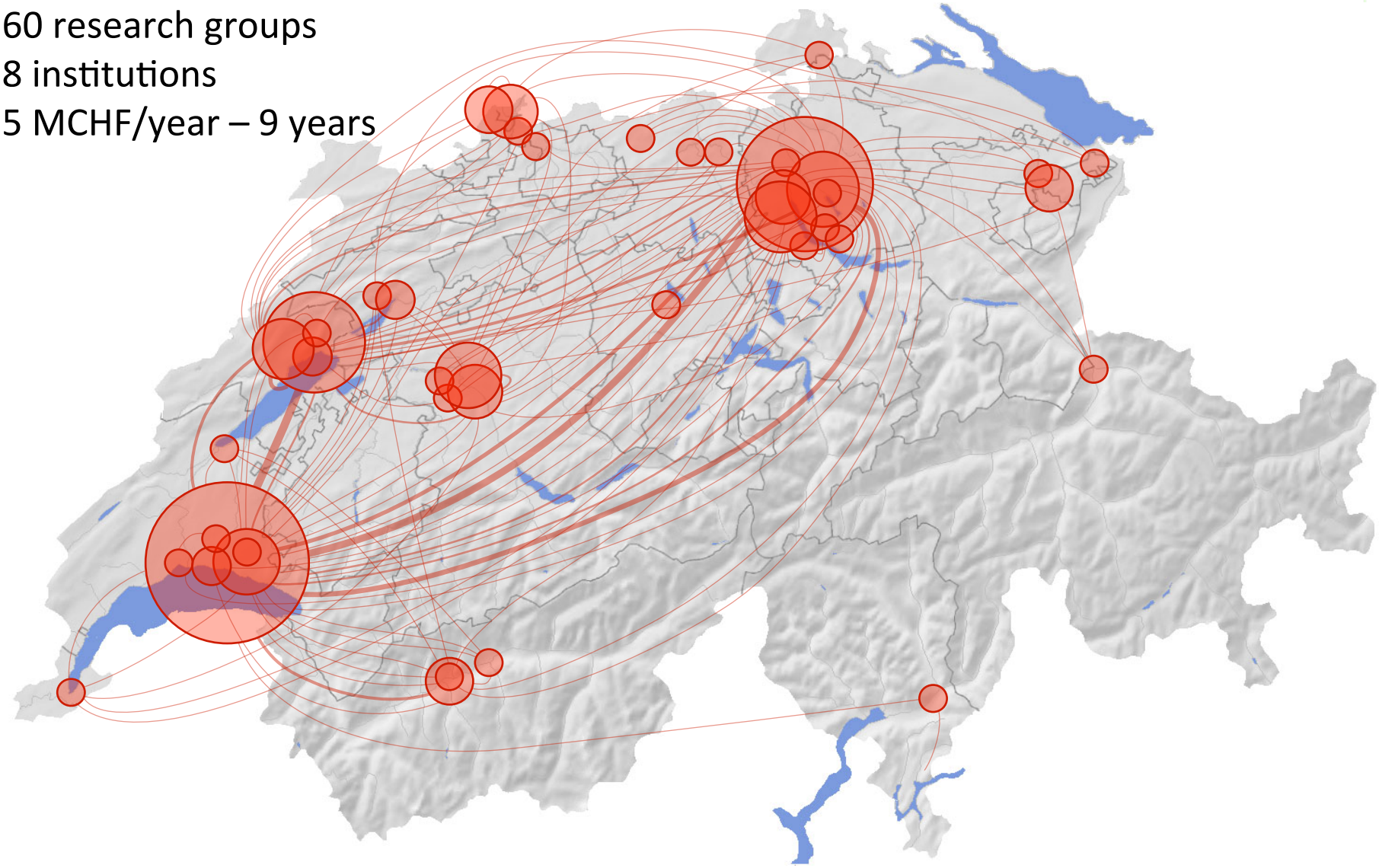
Summary: Opportunities and challenges

- E-health is an unstoppable life-changing trend with unlimited possibilities
- The market is articulated:
  - Some areas are harder than others to penetrate
  - Many problems are still not well understood
  - Ethics and regulations play a major role
- Exciting field for researchers and developers

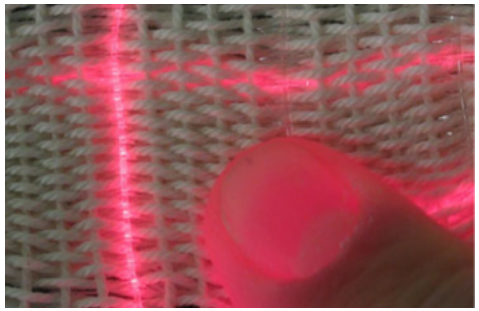
Nano-Tera.ch

160 research groups
38 institutions
15 MCHF/year – 9 years

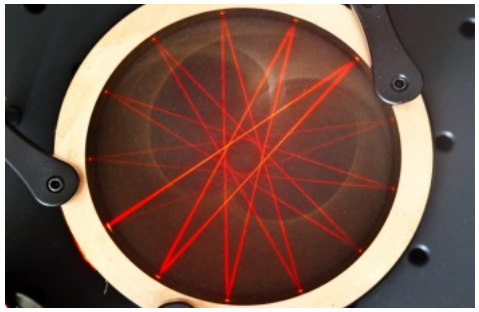


Some Nano-Tera.ch success stories

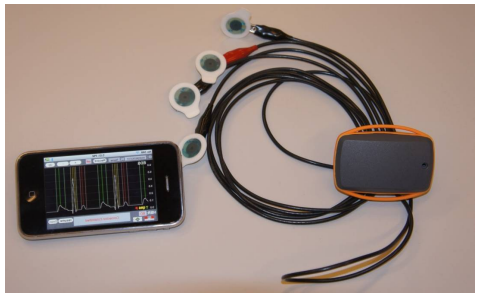
Smart sensor-equipped textiles, able to monitor tissue oxygenation



Optical sensing platform to detect doping agents in saliva

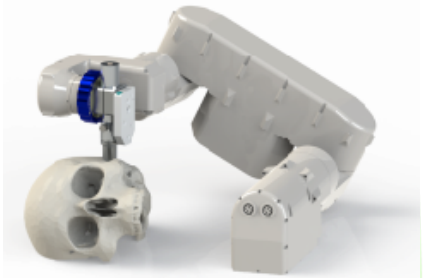


Wearable ECG with wireless data transmission



Integrated neuroprosthesis for motor control & recovery after spinal cord injury

High accuracy surgery for minimally invasive interventions of the ear



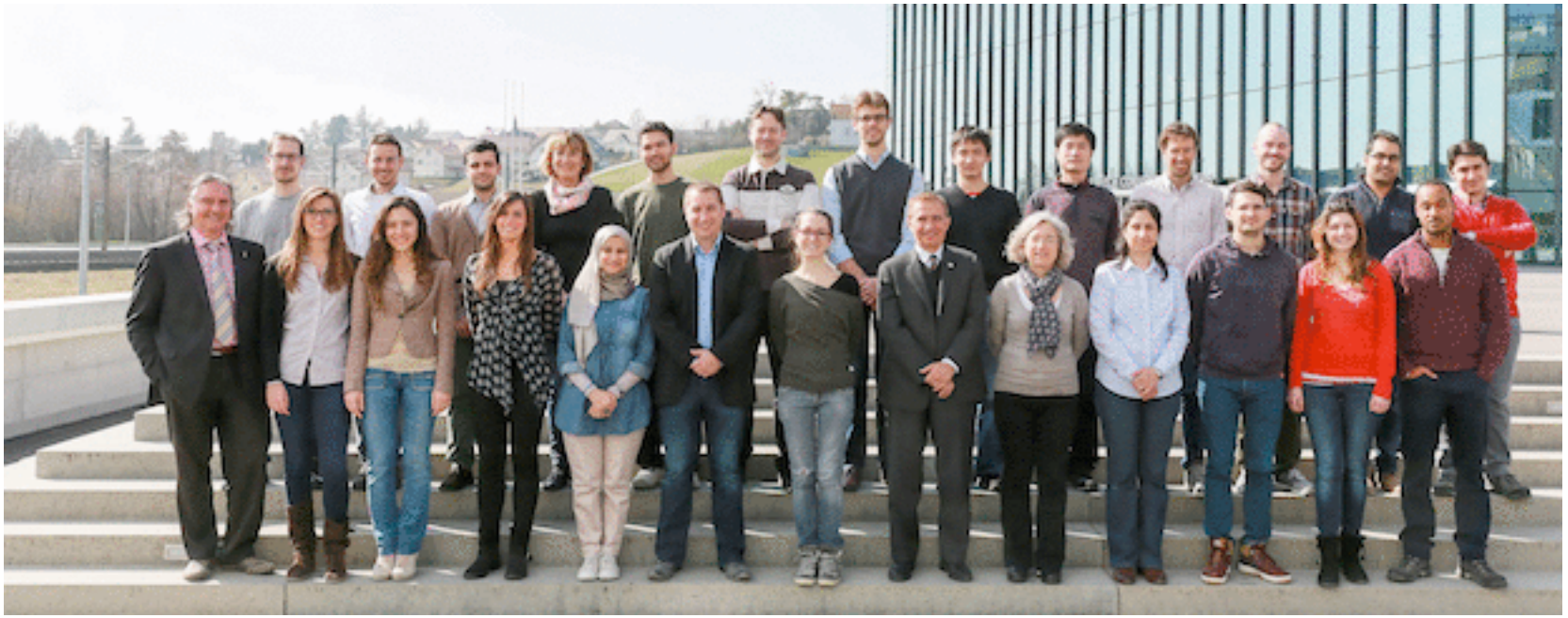
Monitoring obese patients via sensors integrated into smart textiles

[http://www.nano-tera.ch/]

Conclusions

- New electronic health systems and services will be enabled by advances in biology and medicine, in combination with progress in electronics
- The rationalization of health care will provide advanced care to a broader audience at lower cost
- Human factors will still be central to decisions in medicine - decision support will be automated

Thank you



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